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of

Nathan K. Meckel

for

BRAKE DISKS AND METHODS FOR COATING

## FIELD OF THE INVENTION

The present invention pertains generally to coated brake disks and drums and methods for coating brake disks and drums. More particularly, the present invention pertains to brake disks and drums that are coated with a  
5 hard, wear resistant coating. The present invention is particularly, but not exclusively, useful as a lightweight brake disk for use on motorcycles and automobiles.

## BACKGROUND OF THE INVENTION

There are a number of reasons why it is important to minimize the  
10 weight of a brake disk (also sometimes referred to as a brake rotor). First, the weight of the brake disk contributes to the overall weight of the vehicle, and in this respect, affects the vehicle's fuel efficiency and performance. Additionally, the weight of the brake disk adds to the vehicles "unsprung weight" which is generally considered to be the primary source of vehicle  
15 noise and vibration. In addition, less energy is required to rotate a relatively light brake disk during vehicle travel, and accordingly, a reduction in brake disk weight is generally accompanied by an increase in the vehicle's fuel efficiency and performance. A final consideration, which is especially important for brake disks used on motorcycles, is the effect of brake disk  
20 weight on the motorcycle's handling characteristics. In greater detail, gyroscopic inertia is generated when a brake disk is rotated. Specifically, for a given rotation velocity, a heavy brake disk generates more gyroscopic inertia than a light brake disk. This gyroscopic inertia, in turn, must be overcome by the rider to steer the motorcycle. The result is that a heavier  
25 brake disk adversely affects a motorcycle's handling characteristics.

During braking, hydraulic energy is used to press the vehicle's brake pads against the rotating brake disk. The friction resulting from the moving contact between brake pad and brake disk slows the rotation of the brake disk

and decreases the speed of the vehicle. This frictional contact generates heat and causes the contact surfaces on the brake pad and brake disk to wear unevenly. Excessive wear can cause the brake disk to become thin and weak. In some cases, the thinning of the brake disk becomes so severe that  
5 the brake disk is no longer able to support the stresses and heat generated during braking. The result is typically a warped brake disk that can cause undesirable brake chattering.

Conventional brake disks have typically been made of cast iron. Cast iron is relatively inexpensive, machines freely and has adequate strength and  
10 wear resistance at the relatively high brake system service temperatures. On the other hand, cast iron brake disks are relatively heavy due to the high density of cast iron. For example, the density,  $\rho$ , of cast iron is approximately 7.4 gms/cc compared to light metals such as aluminum ( $\rho \cong 2.7$  gms/cc) and Titanium ( $\rho \cong 4.5$  gms/cc). Thus, a significant weight reduction could be  
15 achieved by using a light metal in place of cast iron. In this respect, aluminum has been considered for use in brake disks, however, aluminum's high temperature properties are inadequate for most brake rotor applications.

On the other hand, Titanium and its alloys have relatively low densities and maintain good mechanical properties at the elevated temperatures seen  
20 in most brake disk applications. Titanium alloys are, however, relatively soft and susceptible to wear and galling at the contact surfaces. As indicated above, this wear and galling can lead to thinning, weakening and warpage of the brake disk. It follows that Titanium alloys would be suitable for brake disk application if the contact surfaces could be modified or coated to prevent wear  
25 and galling at these surfaces.

A final factor that must be considered when designing brake rotors is aesthetics. Modern racing motorcycles have rather large diameter brake disks that are plainly visible, especially the front disk. Because of this  
30 visibility, the color and surface appearance of a brake disk can add to or detract from the overall look of the motorcycle. These considerations can affect a purchaser's decision when buying a new motorcycle and when retrofitting a motorcycle with a new brake system.

In light of the above, it is an object of the present invention to provide lightweight brake disks. It is another object of the present invention to provide lightweight brake disks that are coated with a material that is hard and wear resistant. Another object of the present invention is to provide methods for coating brake discs with a hard, wear resistant coating that is aesthetically pleasing.

### SUMMARY OF THE INVENTION

The present invention is directed to coated brake disks and methods for coating brake disks. For the present invention, a typical brake disk is disk-shaped having a central hole (or in some cases multi-holes) to allow the brake disk to be positioned over a hub. The brake disk is further formed with a pair of flat annular surfaces that extend from the central hole to the periphery of the brake disk. These flat surfaces are provided for contact with the brake pads during braking and constitute the wear surfaces for the brake disk.

In accordance with the present invention, the brake disk is made of a Titanium alloy such as Titanium – 6 Aluminum – 4 Vanadium or Titanium – 6 Aluminum – 2 Tin – 4 Molybdenum – 2 Zirconium, and accordingly is relatively lightweight as compared to a similarly sized brake disk made of cast iron. Importantly, a portion of the Titanium alloy brake disk including the wear surfaces is coated with a coating material that is hard and wear resistant. Further, the grey, aesthetically pleasing coating material is preferably deposited on portions of the brake disk that will be visible when the brake disk is installed on the vehicle. In one implementation of the present invention, the coating is deposited on nearly the entire brake disk.

In one aspect of the present invention, the coating includes a first layer of a material having an amorphous structure (i.e. a non-crystalline structure). In a particular embodiment, the amorphous material is a metal such as Titanium, Chromium, Zirconium, Aluminum or an alloy thereof. The first layer is applied directly on the Titanium alloy brake disk. The coating further includes a second layer that overlays and contacts the first layer. The second

layer preferably includes one or more Metal Nitrides, Metal Borides, Metal Carbides and Metal Oxides. More preferably, the second layer includes one or more Nitrides, Borides, Carbides or Oxides of the metal used in the first layer. For example, for a coating having Titanium as the first layer, the  
5 second layer can be Titanium Nitride (TiN). Note; the abbreviations (e.g. TiN) are used herein as a shorthand rather than an exact chemical label, and do not suggest that the stoichiometry of the indicated compound must be exactly as stated in the abbreviation.

In accordance with the present invention, both layers of the coating are  
10 preferably applied using a physical vapor deposition source such as a cathodic arc source with a controlled gas atmosphere. Other operable techniques such as unbalanced magnetron sputtering may also be used. During coating deposition, the brake disks are positioned on a fixture and the fixture is rotated in a planetary movement about a central axis. In greater  
15 detail, the fixture includes three parallel poles that are mounted on a plate and arranged wherein each pole is spaced at an equal distance from the other two poles. A plurality of brake disks can be stacked on each pole, with spacers to separate adjacent disks within each stack. The poles are spaced from each other to allow the brake disks on one pole to overlap the brake disks on an  
20 adjacent pole. The spacers prevent brake disks on one pole from contacting the brake disks on an adjacent pole.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of this invention, as well as the invention itself, both as to its structure and its operation, will be best understood from the  
25 accompanying drawings, taken in conjunction with the accompanying description, in which similar reference characters refer to similar parts, and in which:

Fig. 1 is a perspective view of a motorcycle having a disk brake system;

30 Fig. 2 is a perspective view of a coated disk brake;

Fig. 3 is an enlarged cross-sectional view of a portion of the coated disk brake shown in Fig. 2 as seen along line 3-3 in Fig. 2 showing the coating layers;

Fig. 4 is a front elevation view of a fixture for supporting the disk brakes  
5 during the coating process;

Fig. 5 is a top plan view of a fixture for supporting the disk brakes during the coating process;

Fig. 6 is a schematic plan view and control diagram of a deposition apparatus for use in the invention;

Fig. 7 is a schematic perspective view of a detail of the deposition  
10 apparatus of Fig. 5; and

Fig. 8 is a schematic cross-sectional view of a preferred cathodic arc source, taken along lines 8-8 of Fig. 7.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Referring to Fig. 1, motorcycle 10 is shown that includes a disk brake system. As shown, the disk brake system includes a brake disk 12 that is attached to the front wheel 14 of the motorcycle 10 for rotation therewith. The brake system further includes a caliper 16 having a pair of brake pads that can be selectively applied against the brake disk 12 using hydraulic pressure  
20 to slow the rotation of the brake disk 12 and wheel 14. In a typical setup, the hydraulic pressure is provided by the motorcycle operator using a hand lever mounted on the handlebars of the motorcycle 10.

A better appreciation of a brake disk 12 can be obtained with reference to Fig. 2. As shown, the brake disk 12 is disk-shaped having a central hole 18  
25 to allow the brake disk 12 to be positioned over the hub of the wheel 14 (shown in Fig. 1). The brake disk 12 is further formed with flat annular surfaces 20a,b (see also Fig. 4) that extend from the central hole 18 to the periphery 22 of the brake disk 12. As shown, flat surface 20a is parallel with and opposed to flat surface 20b on the brake disk 12. These flat surfaces

20a,b are provided for contact with the brake pads during braking and constitute the wear surfaces for the brake disk 12.

Referring now to Fig. 3, a coating 24 is shown applied to a brake disk substrate 26. For the brake disk 12, the brake disk substrate 26 is made of a  
5 Titanium alloy such as Titanium – 6 Aluminum – 4 Vanadium or Titanium – 6 Aluminum – 2 Tin – 4 Molybdenum – 2 Zirconium, and accordingly is relatively lightweight as compared to a similarly sized and shaped brake disk made of cast iron. As further shown in Fig. 3, the coating 24 includes a first layer 28 of  
10 a material having an amorphous structure (i.e. a non-crystalline structure). In a particular embodiment, the amorphous material is a metal such as Titanium, Chromium, Zirconium, Aluminum or an alloy thereof.

Continuing with Fig. 3, the coating 24 further includes a second layer 30 that overlays and contacts the first layer 28. The second layer 30 preferably includes one or more Metal Nitrides, Metal Borides, Metal Carbides  
15 and Metal Oxides. More preferably, the second layer includes one or more Nitrides, Borides, Carbides or Oxides of the metal used in the first layer. In a particular embodiment of a coating 24, amorphous Titanium constitutes the first layer 28 and a Titanium Nitride (TiN, Ti<sub>2</sub>N, etc.) constitutes the second  
20 layer 30. With this cooperation of structure, a coating 24 having a service life to exceed approximately 12,000 vehicle miles can be obtained. Note: the abbreviations (e.g. TiN, Ti<sub>2</sub>N, etc.) are used herein as a shorthand rather than an exact chemical label, and do not suggest that the stoichiometry of the indicated compound must be exactly as stated in the abbreviation.

Referring now with cross-reference to Figs. 4 and 5, a fixture 34 is  
25 shown for holding the brake disk substrates 26 during coating. Although the fixture 34 is shown holding five brake disk substrates 26a-e, it is to be appreciated that the fixture 34 is merely exemplary and that fewer or more brake disk substrates 26 could be positioned on a fixture 34. As shown, the  
30 fixture 34 includes three parallel poles 36, 38, 40 that are mounted on and extend from a base plate 42. The parallel poles 36, 38, 40 are arranged on the base plate 42 with each pole 36, 38, 40 spaced at an equal distance from the other two poles 36, 38, 40. With this cooperation of structure, a plurality of

brake disk substrates 26 can be stacked on each pole 36, 38, 40. For example, as shown, brake disk substrates 26a and 26d are stacked on pole 36, brake disk substrate 26c is stacked pole 38 and brake disk substrates 26b and 26e are stacked on pole 40.

5 Continuing with cross-reference to Figs. 4 and 5, it can be seen that spacers 44a-e can be used to selectively separate adjacent brake disk substrates 26 on each pole 36, 38, 40. For the implementation shown, each spacer 44a-e includes a tube 46 and flange 48 allowing each spacer 44a-e to be slid over a respective pole 36, 38, 40 and positioned as desired. In the  
10 implementation shown in Figs. 4 and 5, the spacing between poles 36, 38 is established to allow the brake disk substrates 26 on one pole 36, 38, 40 to overlap the brake disk substrates 26 on an adjacent pole 36, 38, 40. Also for the implementation shown in Figs. 4 and 5, the spacers 44a-e have been sized to prevent brake disk substrates 26 on one pole 36, 38, 40 from  
15 contacting the brake disk substrates 26 on an adjacent pole 36, 38, 40.

Figs. 6 and 7 depict a preferred deposition apparatus 50 for coating the brake disk substrates 26, although other operable deposition apparatus may be used. The deposition apparatus 50 includes a chamber 52 having a body 54 and a door 56 that may be opened for access to the interior of the chamber  
20 52 and which is hermetically sealed to the body 54 when the chamber 52 is in operation. The interior of the chamber 52 is controllably evacuated by a vacuum pump 58 pumping through a gate valve 60. The vacuum pump 58 includes a mechanical pump and a diffusion pump operating together in the usual manner. The interior of the chamber 52 may be controllably backfilled  
25 to a partial pressure of a selected gas from a gas source 62 through a backfill valve 64. The gas source 62 typically includes several separately operable gas sources. The gas source 62 usually includes a source 62a of an inert gas such as argon and a source 62b of Nitrogen gas, each providing gas selectively and independently through a respective selector valve 65a or 65b.  
30 Other types of gas can also be provided as desired, such as gases required to produce borides, oxides and / or carbides.



The pressure within the chamber 52 is monitored by a vacuum gage 66, whose output signal is provided to a pressure controller 68. The pressure controller 68 controls the settings of the gate valve 60 and the backfill valve 64 (and, optionally, the selector valves 65), achieving a balance of pumping and backfill gas flow that produces a desired pressure in the chamber 52 and thence pressure reading in the vacuum gauge 66. Thus, the gaseous backfilled atmosphere within the chamber 52 is preferably a flowing or dynamic atmosphere.

At least two, and preferably four as shown, linear deposition sources 70 are mounted within the interior of the chamber 52 in a circumferentially spaced-apart manner. In Fig. 6, the four deposition sources are identified as distinct sources 70a, 70b, 70c, and 70d, as they will be addressed individually in the subsequent discussion. The four deposition sources 70 are generally rectangular bodies having a greatest rectilinear dimension elongated parallel to a source axis 72. This type of deposition source is distinct from either a stationary point source or a point source that moves along the length of the substrate 26 during deposition procedures.

A support 74 is positioned in the chamber 52. The support 74 produces a compound rotational movement of a fixture 34 mounted thereon. The preferred support 74 includes a rotational carriage 76 that rotates about an axis 78, driven by a rotational drive motor 80 below the rotational carriage 76. Mounted on the rotational carriage 76 are at least one and preferably six, as shown, planetary carriages 82. The planetary carriages 82 are rotationally driven about a rotational axis 84 by a planetary drive motor 86 below the planetary carriages 82. The speeds of the rotational drive motor 80 and the planetary drive motor 86 are controlled by a rotation controller 88. The rotation controller 88 preferably rotates the rotational carriage 76 at a rate of about 1 revolution per minute (rpm).

Continuing with Figs. 6 and 7, for deposition processing of brake disk substrates 26, a fixture 34 as described above can be mounted on the planetary carriage 82, as shown. For commercial operations, a fixture 34 having a plurality of brake disk substrates 26 is typically mounted on each

planetary carriage 82 in the manner described, as illustrated for one of the planetary carriages 82 in Fig. 6.

5 The temperature in the chamber 52 during deposition is controlled using a heater 92 that extends parallel to the deposition sources 70 on one side of the interior of the chamber 52. The heater 92 is preferably a radiant heater operating with electrical resistance elements. The temperature of the heating array is monitored by a temperature sensor 94 such as an infrared sensor that views the interior of the chamber 52. The temperature measured by the sensor 94 is provided to a temperature control circuit 96 that provides  
10 the power output to the heater 92. Acting in this feedback manner, the temperature controller 96 allows the temperature of the heating array to be set. In the preferred processing, the heating array is heated to a temperature of from about 1000°F to about 1700°F.

Fig. 8 illustrates a cathodic arc source 100 used in the preferred form  
15 of the deposition source 70. The cathodic arc source 100 includes a channel-shaped body 102 and a deposition target 104. The deposition target 104 is in the form of a plate that is hermetically sealed to the body 102 using an O-ring 106, forming a water-tight and gas-tight hollow interior 108. The interior 108 is cooled with cooling water flowing through a water inlet 110 and a water  
20 outlet 112. Two spirally shaped (only sections of the spirals are seen in Fig. 8) permanent magnets 114 extend parallel to the source axis 72. Positioned above the deposition target 104 exterior to the body 102 is a striker electrode 118. A voltage  $V_{ARC}$  is applied between the striker electrode 118 and the deposition target 104 by an arc source power supply 120.  $V_{ARC}$  is preferably  
25 from about 10 to about 50 volts.

The metallic material that forms the deposition target 104 is deposited onto the brake disk substrate 26 together with, if desired, gas atoms producing gaseous species from the atmosphere of the chamber 52. For the embodiment describe herein, the deposition target 104 is made of Titanium (Ti) metal.  
30

To accomplish the deposition, an arc is struck between the striker electrode 118 and the deposition target 104, locally heating the deposition

target 104 and causing Titanium atoms and/or ions to be ejected from the deposition target 104. (The deposition target 104 is therefore gradually thinned as the deposition proceeds.) The striking point of the arc on the deposition target 104 moves in a racetrack course along the length of the deposition target 104. A negative bias voltage  $V_{BIAS}$  is applied between the deposition target 104 and brake disk substrate 26 by a bias power supply 122, so that any positively charged ions are accelerated toward the brake disk substrate 26.

$V_{BIAS}$  is preferably from about -30 to about -600 volts. The value selected for  $V_{BIAS}$  determines the energy of ionic impact against the surface of the substrates, a phenomenon termed ion peening. In a typical case,  $V_{BIAS}$  is initially selected to be a relatively large negative voltage to achieve good adherence of the metallic first layer 28 (see Fig. 3) to the brake disk substrate 26.  $V_{BIAS}$  is subsequently reduced (made less negative) when the overlying hard layer is deposited, to achieve a uniform, fine microstructure in the overlying layer. The values of  $V_{BIAS}$  are desirably maintained as low as possible, consistent with obtaining an adherent coating 24.  $V_{BIAS}$  is more positive than -600 volts, and most preferably more positive than -400 volts. If  $V_{BIAS}$  is too negative, corona effects and backspattering may occur at some regions of the brake disk substrate 26. Thus, while higher  $V_{BIAS}$  voltages may be used in some instances, generally it is preferred that  $V_{BIAS}$  be more positive than -600 volts. The cathodic arc source 100 is preferred, but other types of sources, such as sputtering sources, may also be used.

The cooperative selection of the material of the deposition target 104 and the gases introduced into the deposition chamber 52 from the gas source 62 allows a variety of coatings 24 to be deposited onto the brake disk substrate 26, within the constraints discussed previously. The total thickness of the coating 24 is preferably from about 1 to about 10 micrometers. If the coating thickness is less than about 1 micrometer, the physical properties of the coating 24 are insufficient to produce the desired results. If the coating thickness is more than about 10 micrometers, the coating 24 has a high

internal stress that leads to a tendency for the coating 24 to crack and spall away from the brake disk substrate 26 during deposition or during service.

These general principles are applied in preparing the coatings 24 of interest, as described previously in relation to Fig. 3. The coating 24 of Fig. 3 includes an amorphous metallic first layer 28, such as amorphous metallic Titanium, that contacts and overlays the surface of the brake disk substrate 26. The amorphous metallic first layer 28 is deposited by backfilling the deposition chamber 52 with a small partial pressure of about 5 microns of an inert gas, such as flowing argon (flowing at a rate of about 200-450 standard cubic centimeters per minute (sccm) in the apparatus used by the inventors), and then depositing metal, such as Titanium, from the deposition target 104 with  $V_{BIAS}$  about -400 volts. Because the argon does not chemically react with the metal, an amorphous metallic first layer 28 is deposited.

As shown in Fig. 3, a second layer 30, which for the embodiment described herein is a metal Nitride, overlies the amorphous metallic first layer 28. The second layer 30 is deposited by backfilling the deposition chamber 52 with a small partial pressure of about 5 microns of flowing Nitrogen (flowing at a rate of about 150-500 seen in the inventors' apparatus), and then depositing metal, such as Titanium, from the deposition target 104 with  $V_{BIAS}$  about -50 volts. The metal combines with the Nitrogen to produce the metal Nitride in the second layer 30.

While the particular brake disks and methods for coating as herein shown and disclosed in detail are fully capable of obtaining the objects and providing the advantages herein before stated, it is to be understood that they are merely illustrative of the presently preferred embodiments of the invention and that no limitations are intended to the details of construction or design herein shown other than as described in the appended claims.